IV. EXISTING CONDITIONS

A. GEOMORPHOLOGY AND HYDROLOGY

1. Topography and Site Layout

The existing lagoon and riparian system has been extensively altered by filling, construction of levees, alteration of drainage channels, and land use in the Redwood Creek watershed. Figure IV-1 shows the existing site topography, and Figure IV-2 shows a cross-section of the site extending from the beach berm to the upper Green Gulch pasture. The major physical components of the system include Redwood Creek, the dredged channel upstream of the lagoon, and the intermittently tidal lagoon. There are also existing wetlands and channels in the lower Green Gulch pastures.

Redwood Creek has been confined through the site by Pacific Way on the northwest bank and an artificial levee on the southeast bank. The creek flows parallel to the road through an elevated wooded floodplain before turning into a dense willow thicket. This floodplain area is confined between the Redwood Creek levee and a second levee that runs along the Green Gulch pasture, and is 1 to 2 feet higher than adjacent land in the Green Gulch pasture. The creek bed is also fairly high, with invert elevations ranging from +7 feet NGVD at the bridge to +4 feet NGVD upstream of the parking lot.

The lower Green Gulch pasture area is a potential location for restoration. Currently the pasture is separated from Redwood Creek by an earthen levee. The land has been substantially filled, with elevations ranging from about +6 feet in the lower wetlands to +9 in the upper end. Drainage from Green Gulch has been routed into two artificial channels that flow in a linear alignment through the pasture. A third drainage channel conveys runoff into the pasture from the small valley rising above Highway 1 near the riding stables. These channels drain under the levee through two gated culverts into the dredged backwater portion of lower Redwood Creek.

Prior to entering the intermittently tidal lagoon, the creek flows into a deep dredged channel that was used historically to impound water behind a dam that was destroyed in the early 1980's. This steep-banked channel is about 20 to 30 feet wide, with bottom elevations ranging from -3 to +2 feet NGVD. A delta of sediment deposits at the downstream end of the channel prevents tidal inflows and ponds water at about +5 feet NGVD. This delta expanded during the 1982 floods, and is probably a modern feature related to the channelization and impoundment of lower Redwood Creek during the 1960's.

The intermittently tidal lagoon is a dynamic water body that responds to changes in beach morphology and freshwater inflows. The size of the lagoon ranges from about 1.7 acres during peak closure conditions to less than 0.1 acres in October. Bottom elevations are generally at about +2 feet NGVD. Outflows from the lagoon are controlled by the beach berm elevation, which changes seasonally. The beach berm is highest in the southeast, and slopes downward to the lagoon outlet in the northwest. During high winter flows, the outlet is scoured to +1 feet NGVD. In the summer, the beach builds up and the outlet elevation may be as high as +6 feet NGVD (indicating a closed lagoon).

A remnant dune field is located near the high point of the beach berm in the southeast. These dunes, which are created by windblown sand, range in elevation from +13 to +18 feet NGVD.

2. Hydrology and Freshwater Inflows

Information on Redwood Creek flow conditions will be used to analyze the hydrologic regime and water balance for the restoration alternatives, and will be critical in evaluating the feasibility of the alternatives. The following section summarizes existing flows in Redwood Creek.

a. *Watershed Characteristics*

The primary source of freshwater for the lagoon is Redwood Creek, which drains a 7.46 square mile watershed. The watershed, shown in Figure IV-3, originates on the southern slopes of Mt. Tamalpais and includes Fern Creek, Kent Canyon, and Frank Valley. Green Gulch, with a watershed area of 1.26 square miles, also contributes water to the lagoon system. Major land owners include the National Park Service (Muir Woods National Monument and the Golden Gate National Recreation Area), Mt. Tamalpais State Park, and the Green Gulch Farm.

Elevations in the watershed range from about +2 feet at the lagoon to +2600 feet NGVD at the peak of Mt. Tamalpais. Hillslopes are steep, ranging from 15 to 75 percent. Vegetation is composed of mixed conifer forests in the upper valleys (coast redwood, douglas fir), mixed hardwoods, chaparral and grasslands on the slopes, and a corridor of riparian vegetation (willows and alders) along Redwood Creek (Myers, 1990). Most of the watershed is currently reserved for passive recreational uses such as hiking and sight-seeing. The most developed recreational area is at Muir Woods National Monument, which is intensively used by tour groups and other visitors. Other significant land uses include the bulb and heather farms in Frank Valley, stable operations in the Green Gulch pastures, agriculture in Green Gulch, and residential development at Muir Beach.

Soils on the steep hillsides and ridges in the watershed are generally moderately deep loams and gravelly-loams (Soil Conservation Service, 1979). Permeabilities are low to moderate, and the potential for runoff and erosion is high. Alluvial deposits predominate on the valley floors and alluvial fans. These consist of very deep silt loams and clay loams with low to moderate permeabilities. Runoff and erosion potential on the alluvial soils is low, primarily because of the low slopes (2 to 5 percent).

Daily rainfall within the watershed has been recorded by the National Park Service (NPS) at the Muir Woods Ranger Station since 1941. Table IV-1 summarizes the mean annual and monthly rainfall statistics. On average, 95 percent of the annual rainfall occurs from October through April, with the highest rainfall in January and the lowest in August.

The primary losses of water from the restored wetlands will be by evaporation from open water and evapotranspiration from wetland plants. Pan evaporation is one indicator of potential evapotranspiration (PET) losses, and is measured by the Marin Municipal Water District at the Lagunitas Reservoir. Table IV-1 summarizes mean annual and monthly evaporation statistics. Using a pan coefficient of 0.7 to convert pan evaporation to potential evapotranspiration, PET estimates range from 0.27 inches in January to 5.11 inches in July.

b. *Summary of Existing Hydrologic Data on Redwood Creek*

With the exception of data collected for this study, there has been no continuous streamflow measurement on Redwood Creek. During the 1960's the USGS measured annual peak flows in Redwood Creek upstream of Frank's Valley (USGS, 1970). The USGS also measured flows in Redwood Creek and Green Gulch twice per year between 1985 and 1988. These historic flow data are summarized in Table IV-2.

Streamflows were monitored for this study at the Pacific Way bridge from March 1992 through September 1993. During the rainy season, flows were estimated from recorded stage data using a rating curve developed from velocity meter surveys. Because of the low flow rates in the summer, a v-notched weir was used to measure flows from August through October 1992. The 1993 storms deposited gravel throughout the reach, and reconfigured the channel bed. As a result, we were unable install the weir for the summer of 1993 without losing significant volumes of water to seepage in the newly-deposited gravel beds. Velocity meter surveys were therefore used to characterize flows in July, August, and September of 1993.

c. *Analysis of Redwood Creek Flow Characteristics*

The hydrologic regime of Redwood Creek is similar to that of many Northern Coastal streams. Early season storm flows are comprised primarily of direct storm runoff, and recede quickly after rainfall ends. By January groundwater storage is sufficient to maintain high baseflows, and post-storm recessions can last for over 7 days. Flows in the late spring and summer dry season are derived from groundwater and springs in the upper portion of Redwood Canyon. Limited groundwater storage is available in the alluvial deposits in the lower valleys, and during the dry season the creek commonly loses water to groundwater in the lower reaches in Franks Valley.

An analysis is currently being conducted on the impacts of upstream wells on Redwood Creek flows (PWA, 1994). The Muir Beach Community service well pumps about 0.13 cfs for about 14 hours each night. The two Banducci wells operate intermittently depending on irrigation needs; water meters on these measured an average daily water usage of 0.03 cfs in September 1993 (averaged over pumping and non pumping periods). When Banducci's wells are operating, they have a combined capacity of about 0.4 cfs.

Figure IV-4 shows the recorded daily average flows at the Pacific Way bridge for March 1992 through September 1993. The 1991-92 season was the last of six consecutive drought years. Groundwater storage was sufficient to maintain flows greater than 1.0 cfs through April, but flows dropped to below 0.5 cfs by June and below 0.01 cfs by September. In September and October aquatic habitat existed primarily in isolated pools fed by underflow through the creek gravel beds.

The winter of 1992-93 was a wet year, with 42 inches of rainfall recorded at Muir Woods from October 1992 through September 1993 (about 20% higher than average). The first large storms occurred in December, followed by nearly 14 inches of rain in January. The largest storm event occurred on January 20th, with a peak instantaneous flow rate of 370 cubic feet per second (cfs). By the end of January, there was sufficient water in groundwater storage to maintain between-storm baseflows of 10 to 30 cfs.

The net effect of the higher rainfall in 1993 was to delay the dry-season recession of streamflows by about 1-month (relative to the 1992 dry season). Flows remained above 1 cfs through June of 1993, and did not drop below 0.5 cfs until the end of July. By the end of the monitoring period (October), flows had decreased to 0.08 cfs.

Historical USGS data (Table IV-2) show peak annual storm flow ranging from 300 to 1,800 cfs, which are generally higher than the 1993 peak flow of 370 cfs. USGS flows measured in the early summer from 1986 - 1988 are generally on the order of 0.7 cfs, which is similar to summer flows measured for this study in 1992 and 1993.

Table IV-3 summarizes recorded monthly Redwood Creek flow volumes at Pacific Way, and compares these to potential evapotranspiration losses between Pacific Way and the tidal lagoon. The creek delivered over 8,800 acre-feet of water to the site from October 1992 to September 1993. 95 percent of this volume occurred between December and April. The minimum observed 30-day flow volume of 0.54 acre-feet (0.01 cfs) occurred in the late summer of 1992. The minimum observed 5-month inflow volume was 39 acre-feet (0.13 cfs).

To establish the recurrence interval of the observed low flows, a flow-duration curve was derived for Redwood Creek from historical data collected by the USGS at Arroyo Corte Madera del Presidio. This creek drains 4.7 square miles of primarily undeveloped land, and has 19 years of daily average flow data. The Redwood Creek flow-duration curve, shown in Figure IV-5, was derived by scaling the Arroyo Corte Madera flows by the ratio of the two drainage areas. Based on this information, the minimum observed 30-day Redwood Creek flow volume during 1992 would occur on average once every 13 years. The 1992 minimum observed 150-day flow volume would occur once every 20 years. Thus, the data from the 1992 dry season represents a relatively severe and infrequent drought condition.

In 1993, the minimum 150-day average flow was about 1.4 cfs, which has a recurrence interval of less than 1 year. The data from 1993 thus represent a more typical summer flow condition.

Downstream of Pacific Way the creek flows through a 5-acre stand of riparian and wetland vegetation before entering the intermittently tidal lagoon. Data summarized by Johns (1989) indicates that willows typically use on the order of 35 inches of water per year, much of which is drawn directly from shallow groundwater and creek flow. Assuming that all water used by riparian plants over this 5-acre area is drawn directly from the creek, Table IV-3 shows that inflow volumes greatly exceed losses for most of the winter, spring, and early summer. However, in the late summer and early fall of drought years evapotranspiration extracts as much as 50% of the inflow volume.

Green Gulch Creek was not monitored as part of this study. Previous USGS monitoring efforts recorded storm flows as high as 10 cfs. The watershed has limited groundwater storage, and flows are diverted and stored in two small reservoirs for irrigation. As a result, the creek contributes no observable flow to the lagoon during the dry season.

3. Redwood Creek Channel Morphology

Figure IV-6 is a profile of the creek bed from Pacific Way to the tidal lagoon, and Figure IV-7 shows the channel cross-section immediately upstream of the bridge. Upstream of the dredged channel the creek bed consists of alternating pools and gravel beds, and slopes at about 11 feet per mile. The dredged channel bottom is uneven but has little or no slope, and consists of fine silts and organic material.

Confinement of the creek between levees as well as the constriction caused by the Pacific Way bridge have concentrated flood flows and altered the geomorphic regime of the creek. This results in scour near the bridge, as illustrated in Figure IV-7, and sediment deposition downstream. As the creek enters the deep dredged channel near the parking lot, sediment is deposited in a delta that slopes downward from the northeast to the southwest bank. This deposit is gradually filling in the dredged channel, and has raised bottom elevations by over 2 feet in some locations.

A larger sediment delta lies immediately upstream of the tidal lagoon. This delta expanded during the 1982 floods, and has become heavily vegetated during the recent drought years. Although historically there has always been a sediment deposit at this location, the existing delta is higher and consists of less mobile fluvial deposits. The expansion of this delta is probably a result of the altered sediment transport characteristics of the upstream channel (due to levee construction and dredging of lower section of the creek near the footbridge). The delta effectively acts as a barrier between the creek and the tidal lagoon, and backs flows up into lower Redwood Creek at an elevation of about +5 feet NGVD.

The creek levee is failing in several locations downstream of Pacific Way, and large storm flows spill over the levee into the wooded floodplain. Storm flows also commonly spill overbank immediately upstream of the bridge and flow across Pacific Way into the Green Gulch pasture. During the 1993 rainy season this overbank flooding was increased when several trees were undercut and fell across the channel. Because of a more favorable gradient, it is likely that the channel will eventually scour through the levee and floodplain and shift into the backwater portion of the dredged channel. The current creek channel would then be abandoned and fill in with riparian vegetation.

4. Flood Hazards

Lehre (1974) derived a flood-frequency relationship for Redwood Creek based on 12 years of peak flow measurements collected at the Franks Valley bridge. Based on this, the 100-year flood in Redwood Creek would have a peak discharge of about 3300 cfs. The 10-year peak would be about 2000 cfs, and the 2-year peak would be about 800 cfs.

Flood hazards may result in the area due to storm flows in Redwood Creek and coastal storm surge tides. The Federal Emergency Management Agency (FEMA) Flood Insurance Study for Marin County designates most of the lowlands between the lagoon and the Pacific Way bridge as subject to flooding from Redwood Creek during a 100-year event, based on approximate methods (Figure IV-8). The 100-year floodplain extends up into Franks Valley and Green Gulch. FEMA also shows the beach, lagoon, and picnic area as subject to coastal flooding during 100-year high tides.

There is considerable anecdotal evidence that the homes along Pacific Way flood frequently. The creek jumps its banks upstream and downstream of the bridge, and flows over the low point in the road between the bridge and the Pelican Inn. Much of this flooding is due to the loss of flood storage by filling, and the confinement of the creek through the Pacific Way bridge and various levees. Flooding also occurs because the creek outlet to the beach is constricted between the raised parking lot and the pasture levee. The capacity of the channel at this location is insufficient to convey large storm flows (recurrence interval of 2 years or greater), and the backwater effects of this constriction can increase flood hazards upstream along Pacific Way. Under natural conditions, a dune field probably played a similar role as the parking lot, but backwater flooding was less severe because of the lower elevations of the historic marsh, the erodibility of dune sands during storms, and the lack of levees in the creek floodplain.

Flooding can also be caused by tsunamis, which occur when the sea bottom shifts during an earthquake. A study by the U.S. Army Corps of Engineers (COE) (Garcia *et al.*, 1975) estimates that a 100-year tsunami wave would runup to an elevation of 8.2 feet above mean sea level at the entrance to San Francisco Bay. At Muir Beach this would flood most areas seaward of the parking lot, and bring salt water into lower Redwood Creek.

5. <u>Wave Climate and Beach Morphology</u>

Waves on the California coast are comprised of both seas and swells. Seas consist of small wavelength waves created by local winds, while swells are long waves that originate from distant storms in the North Pacific Ocean. Figure IV-9 shows average annual wave roses for both sea and swell for the COE San Francisco hindcast station (COE, 1965). Swells on the north coast originate primarily from the west and northwest. The most frequent seas also originate from the northwest, but there are significant periods where seas come from the southerly directions.

Muir Beach is located on the north end of a small crescent-shaped embayment, and is protected from waves from all but the southerly direction by a prominent headland. Waves from the predominant northwest direction must diffract around this headland to reach the beach, losing considerable energy in the process. As a result of this diffraction, the lowest wave energy tends to occur on the northwestern end of the beach. The beach is directly exposed to waves resulting from southerly seas.

The location of the beach and headland also has important implications for sand movement. Along much of the coast the net movement of sand occurs longshore from north to south (parallel to the shoreline), due to the predominant northwesterly waves. The headland acts as a barrier to this longshore transport of sand. As a result, sand movement at Muir Beach is driven by on- and off-shore rather than longshore transport. This also means that the primary source of sand at the beach is probably a localized littoral cell derived from Redwood Creek sediments.

The erosive potential of waves can be characterized by wave power and wave steepness. Wave power is the rate at which energy is transmitted per unit crest length of the wave, and is calculated in deep water as follows:

$$P = (\gamma)\,\frac{H^2 L}{16T}$$

where

P	=	wave power per unit crest length (ft-lbs/ft-s)
γ	=	unit weight of seawater (64 lbs/ft^3)
H	=	wave height (ft)
L	=	wave length (ft)
T	=	wave period (s)

Wave power is indicative of the power available to transport sand, either onshore or offshore.

Wave steepness, defined as the ratio of wave height to wave length, indicates whether the wave climate favors beach erosion or beach buildup. Winter waves tend to be steep, resulting in net erosion and transport of sand offshore. Summer swells tend to be relatively long and shallow waves, resulting in beach buildup and onshore transport of sand.

Figures IV-10 and IV-11 plot monthly average deep water wave power and wave steepness from May 1992 through April 1993 for the National Oceanic and Atmospheric Administration (NOAA) wave buoy offshore of San Francisco. Although these data do not necessarily represent actual wave characteristics at Muir Beach, they do provide a description of the general seasonal variability of wave climate. Wave power was generally highest in March and April of 1993, and lowest in June and July of 1992. Wave steepness was lowest during the lagoon closure periods (July through November), and in March 1993.

To quantify how wave climate shapes the beach morphology at Muir Beach, monthly surveys of the beach were performed for this study. Figure IV-12 compares a winter and summer profile of the beach berm, parallel to the water line. The beach berm slopes downward from the southeast to the northwest, with the lowest point at the lagoon outlet. This low point is also the point of lowest wave energy along the beach. The winter profile also shows several eroded gullies in the center of the beach, resulting primarily from wave overwash into the lagoon. During the winter, the lagoon is open and the low point in the beach berm is at about +1 foot NGVD. In the summer, the lagoon closes and the low point builds up to +6 feet NGVD.

As shown in cross-section on Figure IV-13, the winter beach cross-section features an eroded berm and relatively flat offshore slope. In the summer the beach rebuilds and slopes up to a relatively high berm. During our study, the beach exhibited an eroded winter profile from December 1992 through February 1993. The beach berm built up rapidly to a summer profile in March, when a combination of low wave steepness and high wave energy resulted in strong onshore transport of sand.

6. Lagoon Hydrodynamics and Morphology

Lagoon closure is a function of creek flow rates, wave climate, and tidal conditions. The timing and frequency of closure are very important factors in the migration of anadromous fish. The following analysis characterizes the relative importance of creek flows, wave climate, and tides so that we can predict the impacts of restoration alternatives on tidal lagoon habitat.

a. *Overview of Lagoon Processes*

Coastal lagoons are highly dynamic features that are shaped by beach berm evolution, wave climate, tidal flows, and freshwater inflows. The vast majority of previous work has focused on lagoons larger than 10 acres in surface area, and to our knowledge this is the first attempt to perform a detailed characterization of a small coastal lagoon system.

Traditional research on lagoons has dealt with characterization of lagoon opening and closure dynamics. Lagoon outlets are maintained and scoured by a combination of tidal and freshwater flows. In larger systems, the tidal component (quantified by the tidal prism) tends to control lagoon opening and closure frequency. Conversely, the freshwater inflow component is dominant in small lagoon systems.

Wave dynamics and sediment transport also play an important role by determining the shape and elevation of the beach berm. During the winter, the wave climate erodes the beach and flows are sufficient to maintain an open lagoon inlet. In the summer, waves transport sand onto the beach and the lagoon may close depending on tidal and inflow conditions.

Closed lagoons fill with freshwater inflows, and lose water to evaporation and seepage through the beach berm. The lagoon will breach when the ponded elevation exceeds the beach berm height. In systems with high summer flows this may occur several times in a season. In lagoons where losses exceed summer inflows the lagoon remains closed until winter storms breach the outlet. Lagoons may also be artificially breached to prevent upstream flooding.

A number of studies have attempted to quantify and predict lagoon opening and closure dynamics. The most widely applied of these is the Johnson Criteria, based on data from over 30 west coast lagoons (Johnson, 1973). This criteria relates closure frequency to deep water wave power and tidal prism, and is plotted in Figure IV-14. Applying this criteria to Big Lagoon (with a potential diurnal tidal prism of about 90,000 cubic feet) shows that tidal flows in this case are not sufficient to maintain a stable opening. In fact, doubling the size (or tidal prism) of the lagoon would have little impact on closure frequency. The existing tidal lagoon will therefore remain open only as long as freshwater inflows are sufficiently high to scour an outlet channel through the beach berm.

b. *Summary of 1992-93 Lagoon Conditions*

Water levels in the lagoon were monitored over an 18-month period to identify the hydrologic response of the lagoon to inflows and tidal action. The morphology of the lagoon was monitored through two detailed surveys, one in December 1992 and one in June 1993. In addition, selected cross-sections were surveyed during each monthly site visit.

Table IV-4 summarizes observed lagoon conditions during the study period, and correlates lagoon behavior to tidal range, wave power, wave steepness, berm elevation, and freshwater inflow rate. During the winter rainy season freshwater inflows ranged from 10 cfs between storms to over 400 cfs during storms. These flows were sufficient to scour and maintain an outlet channel at elevations as low as +1 feet NGVD. During our monitoring period, the lagoon was breached by a series of storms in December 1992, and remained open and partially tidal into February 1993.

In the late winter and spring the lagoon entered into several transitional modes. During February and March of 1993, the wave climate shifted to relatively long waves with high power, resulting in strong onshore sand transport and closure of the lagoon from tidal action. At the same time, freshwater inflows remained sufficiently high to maintain an open channel through the beach. The net result of this was a high beach with an open lagoon outlet perched above +3.5 feet NGVD. The outlet during this period functioned as a non-tidal river channel discharging across the beach.

By May of both monitoring years, the outlet had again scoured down to about +3 feet NGVD, and the lagoon was subject to tidal influence during spring higher high tides. Freshwater flows at Pacific Way were at about 1 cfs. During these periods the lagoon closed for 3-10 hours each day from sand deposited on the flood tide. Breaching occurred daily as water levels built up and overtopped the beach berm. As flows dropped below 0.5 cfs, the period of closure became longer (12 or more hours). Finally, an extended period of strong onshore sand transport closed the lagoon for the remainder of the summer. This occurred in late June of 1992 and late July of 1993 (primarily because inflows remained high for a longer period in 1993).

Upon closure, the lagoon initially filled to as high as 5.5 feet NGVD, and covered nearly 2 acres. However, by August of 1992 and 1993 losses from evaporation and seepage exceeded inflows and the lagoon rapidly receded to less than 0.1 acres. The diminished lagoon remained closed until breached by storms in November and December.

Sediments for grain size analysis were taken in conjunction with benthic invertebrate sampling in the lagoon. Only qualitative observations of sediment texture were made in March; quantitative sediment analysis was done for the May and September samples (Appendix B). Percentage of fine sediments in all stations was very low (> 1%) on all three sampling dates. The most obvious trend was a shift from gravel size sediments at two of the three tidal lagoon stations during March and May to sand size sediments at all three stations in September. This is probably due to seasonal fluctuation in rainfall and stream flow including intense winter and spring rains during late 1992 and early 1993. As a result, the creek channel was strongly scoured leaving a lagoon deposit of heavy gravel and pebbles. By September, creek flow was greatly reduced and wind blown sand covered the coarse deposit.

c. *Key Observations on the Dynamics of Big Lagoon*

The monitoring data collected for this study show that the existing tidal lagoon behaves primarily as a small coastal lagoon, in which closure is dependent almost entirely on wave climate and freshwater inflows. Tidal flows have a limited role in maintaining the lagoon outlet, and enlarging the lagoon would have little effect on closure frequency.

The lagoon exhibits four seasonal modes of behavior, defined as follows:

1. <u>Fully Closed:</u> The lagoon outlet is entirely filled with sand, and the beach berm is at 6 feet NGVD or higher (Appendix D). The lagoon may fill initially with freshwater, but eventually diminishes due to

evaporation and seepage. This mode occurs following closure in the early summer, and persists until the first major winter storms.

2. <u>Open, Nontidal:</u> Periods of strong onshore sand transport build the beach berm up to a level that prevents tidal inflow. At the same time, freshwater inflows are sufficient to maintain an open channel across the berm. This occurred in March of 1993, and is indicated by a constant (nonfluctuating) water level and an open outlet channel (Appendix D).

3. <u>Open, Tidal on Spring Tides:</u> The beach berm is built up to a level that allows tidal inflows only during spring higher high tides; neap tides do not enter the lagoon. Freshwater inflows are still sufficient to maintain an open outlet. This occurs in the spring and early summer prior to full closure (e.g. May 1992, Figure IV-15).

4. <u>Open, Partially Tidal:</u> The outlet channel is scoured to as low as +1 feet NGVD, allowing tidal inflow during all tidal cycles. Low tides are still truncated. This mode occurs during the winter when inflows are very high and the beach profile is eroded by winter storm waves (for example, January 1993, Figure IV-16).

Two summer closure events were observed in this study. These occurred when flow rates at Pacific Way dropped below 0.5 cfs, thus allowing periods of onshore sand transport to close off the lagoon. Onshore transport occurred in the summer when deep water wave steepness dropped to about 0.01.

The lagoon re-opens in response to large early winter storm flows, generally in late November to December. The first winter storms fill the lagoon, and when the water surfaces elevation overtops the beach berm, the lagoon breaches. At Big Lagoon the beach berm is at about +6 feet NGVD when the lagoon is closed, and the lagoon has a storage capacity of about 3.5 acre-feet. A daily average flow of about 2 cfs is sufficient to fill and breach the lagoon.

7. <u>Groundwater</u>

Groundwater was monitored monthly in five shallow monitoring wells located in the Green Gulch pasture (Figure IV-17). Based on soil corings, the stratigraphy of this area consists of over 6 feet of fill material underlain by lagoonal silts and sands. The fill material is comprised of pebbly silty sands and sandy silts. Groundwater is present in both the fill material and the historic lagoon deposits.

As shown in Figure IV-18, water levels were at or near the surface during from December 1992 through March 1993. Much of the pasture was ponded water during this period, due to high flows in Green Gulch. Minimum water levels occurred in October 1992 at 3 to 4 feet below the ground surface. Note that much of the ponding in the pasture is related to blockage of the two culverts that drain through the levee into Redwood Creek. If these were cleared and repaired, winter water levels in the pasture would drop.

In the winter groundwater levels followed the surface topography, with the highest elevations in Green Gulch and the upper pasture at wells 1, 3, and 4. In the summer the highest water levels were at wells 1 and 2 (adjacent to the levee), and groundwater flowed from the upper pasture areas nearest the creek towards Green Gulch and the lower pasture.

An important observation from Figure IV-18 is that the minimum water levels in well 5 are more than 1-foot lower than those in the Redwood Creek dredged channel (which ponds at about 5-feet NGVD).

8. <u>Water Quality</u>

A summary of existing water quality data is provided to 1) characterize the suitability of water in the pools and lagoon for aquatic life, and 2) identify the nutrient and bacterial levels that are causing the existing water quality problems in the pools. Salinity data are also provided to gain insight into the extent of tidal influence.

a. *Salinity, Dissolved Oxygen, and Temperature*

Salinity, dissolved oxygen, and temperature were monitored monthly in the tidal lagoon and at selected stations in Redwood Creek from August 1992 through September 1993. Figure IV-19 shows salinities, dissolved oxygen, and temperature in the tidal lagoon for the monitoring period.

The lagoon was stratified in June and July of 1992 because of saline inflows during high tides. Once closed, the lagoon became well-mixed and slightly brackish until September 1992, when the lagoon stratified with bottom salinities as high as 15 ppt. This stratification persisted until December of 1992. Because the outlet was closed during this period, the source of the bottom salinity would have to be either wave overwash or seepage through the beach berm.

In 1993, the lagoon remained fresh until July, when a combination of low freshwater flows and tidal inflows through the opening created stratified conditions. By September after closure the lagoon was once again primarily fresh and well mixed.

No salinity was observed upstream of the tidal lagoon in Redwood Creek, indicating that the sediment delta acts as an effective barrier to tidal inflows. The key water quality issue in the lower reaches of the creek is therefore dissolved oxygen. In the late summer, creek flows can drop below

0.01 cfs, and water persists only in isolated pools. The largest pool occurs in the artificial backwater channel, where water is stored behind the sediment delta upstream of the lagoon. Depths in this area can be as high as 8 feet, and the summer low flows provide limited circulation. In addition, nutrients and other pollutants flow into the channel from Redwood Creek and Green Gulch. These factors contribute to algal blooms, and result in eutrophic, low dissolved oxygen conditions.

Figures IV-20 and IV-21 show dissolved oxygen in the dredged channel at 1) the footbridge, and 2) at the upstream end of the backwater reach. Water quality criteria for aquatic organisms generally recommend dissolved oxygen levels about 5 mg/l. Dissolved oxygen at the footbridge generally remained above 5 mg/l, even in the summer. However, dissolved oxygen in the backwater portion of the channel dropped below 5 mg/l by June, and reached a minimum level of less than 1 mg/l. This poor water quality has important implications for juvenile fish habitat.

Upstream of the dredged channel dissolved oxygen in Redwood Creek generally ranged from about 6 mg/l in the summer to over 10 mg/l in the winter.

b. *Nutrients and Coliform Bacteria*

As summarized in Table IV-5, water quality data from a variety of sources are available for locations along Redwood Creek and Green Gulch. Most of these studies focused on pollutants that would be anticipated from stables and agricultural activities, such as nitrates and nitrites, fecal coliform, and phosphorus. The USGS sampled water quality twice per year from 1986 through 1988 at several locations in the Redwood Creek watershed. Harding-Lawson and Associates collected samples from November through March 1991 near the Muir Beach Community Services Wells (Harding-Lawson and Associates, 1991). Philip Williams and Associates sampled water quality at various locations during the summer of 1993 and a December 1993 storm to identify potential pollutant sources under a separate contract for the NPS.

Upstream of the stables and flower farms in Franks Valley fecal coliform measurements on Redwood Creek range from 2 to 110 MPN/100 ml, with most values at about 30 MPN/ml. Downstream of the stables and flower farm these levels increase to between 140 and 540 MPN/ml in dry weather samples. This increase can probably be attributed to horses. At the Pacific Way bridge coliform levels in the creek increase dramatically to as high as 8000 MPN/ml, and generally exceed the water quality standard of 200 MPN/100 ml for contact recreation (San Francisco Bay Regional Water Quality Control Board, 1990). Leaky septic tanks and leach fields along the creek floodplain are the probably sources of this increase.

Excessive nutrient levels (nitrates, phosphorus) can lead to algal blooms and low eutrophic dissolved oxygen levels. The levels that course these problems are generally site-specific, and there are no State ambient water quality standards for these parameters. However, natural levels of nitrates are generally less than 0.1 mg/l as N.

Nitrates and nitrites in the creek are highest in the winter, at levels ranging from 0.1 to 0.58 mg/l. Winter levels are similar between the upstream end of Franks Valley and the Pacific Way bridge. During the dry season nitrates and nitrites are less than 0.012 mg/l upstream of the Franks Valley stables, and between 0.01 and 0.02 downstream of the flower farm. Nitrogen levels change little between the flower farm and the Pacific Way bridge, although one value of 0.39 mg/l was reported by the USGS in June of 1988.

Samples from Green Gulch indicate that runoff from horse and agricultural activities in this area are significant sources of coliform and nitrogen. In the winter, coliform levels from Green Gulch range from 10 to 500 MPN/ml and nitrate and nitrate levels range from 0.68 to 1 mg/l. In the summer coliform levels range from 3 to 240 MPN/ml, while nitrogen levels are generally below detection limits.

Limited nutrient sampling by Dr. Jerry Smith in 1992 and 1993 found both phosphorus and nitrogen to be present in the pools at most times (Table IV-6), indicating that excess nutrients are present in the pools, despite the abundance of aquatic plants and algae. Nutrient sampling at the road bridge at the entrance to Muir Beach usually showed significant nitrogen and phosphorus, including nitrate nitrogen levels of 1.6 mg/l during rain on 4 June 1993 and 1.8 mg/l during fair weather on 24 June 1993 (Table IV-6). On the second date, no nitrate nitrogen was detected 0.6 miles upstream (downstream of the diversions) suggesting that the nitrate source was downstream of the agricultural operations in Franks Valley. On 17 June 1992 a very high phosphate phosphorus level of 1.5 mg/l was detected at the road bridge at Muir Beach (Table IV-6); such a high level is probably an indication of phosphate fertilizer runoff. The main channel from Green Gulch, flowing through the horse pasture, often had high nutrient levels (Table IV-6). The very low flow rate in that channel probably makes those inputs minor during the summer. However, during spring or summer rain those inputs may be significant.

B. ECOSYSTEMS

1. Wetland and Former Wetland Habitats

The existing wetlands and former wetland habitats which once comprised the historic Big Lagoon ecosystem were monitored to document the existing biological communities and general seasonal patterns of change. The biological monitoring focused on major wetland-dependent floral and faunal groups to establish a qualitative and quantitative description of species composition and relative abundances. The description was made to help develop restoration alternatives for Big Lagoon, and also to act as a baseline for documenting how wildlife communities change because of restoration. The major groups include plant assemblages, aquatic invertebrates, fishes, reptiles, amphibians, and birds. Except for reptiles, these groups depend on existing wetland habitats and are very sensitive to increases or decreases in the quality and quantity of wetland. For each group, monitoring sites were selected to characterize different types of existing habitats or potential restored habitats within the larger wetland complex.

a. *Vegetation*

Five major plant associations in the lowland were quantitatively sampled. They were, with approximate area, pasture (8 acres), salt marsh (1 acre), disturbed (1¼ acres), riparian (4¼ acres), aquatic (nearly 1 acre), and dune (1½ acres). The riparian corridor included areas of low, aquatic herbaceous vegetation where it graded into the tidal lagoon and in the quiet water along the levee. Aquatic vegetation also grew in the pasture pond and ditches. The area covered by aquatic vegetation was not large, but the association was distinct and warranted special treatment. The disturbed association occupied part of the salt marsh, which it was invading, and the levee edge. The name refers to the weedy and invasive nature of the plants comprising that association. The area of the dune association included only the southeast portion of dune, not the main spit separating lagoon from sea. Upland habitat of modified coastal scrub grew adjacent to the site on the surrounding hills. Eight transects were established for quantitative seasonal surveys along the major subhabitats within the existing and historic wetland: one in Kikuyu grass (to represent disturbed habitat), one in the salt marsh, one in the lower riparian (or aquatic), and five in the meadow habitat. An additional transect was established in the upland (Figure IV-22). Details about qualitative and quantitative survey methods are in Appendix B.

Big Lagoon is largely vegetated by a combination of riparian forest and pasture plants, both native and alien species. Of 181 species found on all surveys, 55% (n = 100) were native and 45% (n = 81) were alien species (Table III-3). Predictably, most alien vegetation grew in areas currently impacted by human activity: roadsides, trailsides, picnic areas and pastures. In contrast, species number and cover of native species were greater in less-impacted riparian, aquatic and upland habitats. In general, alien species (annual grasses and clover) dominated pasture transects, and a mix of native species and alien weeds (particularly invasive Mediterranean annual grasses) vegetated habitat edges such as the levee. Riparian, aquatic, dune and marsh habitats were comprised mainly of native species.

- *Riparian Corridor*

The main riparian forest at Big Lagoon encompasses the area between the present and former creek channels, bounded by the levee, vehicle access road and parking lot (Figure IV-22). Aerial photos indicate this vegetation is between 30 and 40 years old. This habitat is recovering from the massive denuding of vegetation due to agriculture. In addition, small alders and some willows grow along drainage ditches in the pastures, and on sediments which were deposited downstream of the footbridge a decade ago.

Riparian vegetation was composed primarily of a dense canopy of red alders, arroyo willows and yellow willows, and an understory of thimbleberry and elderberry mixed with thick stands of nettles, native morning glories and alien German and English Ivy. Lady ferns lined the bank above the stream and patches of bulrush grew in the water.

Nearly ⅓ (31%) of the 51 species identified in the riparian transect were non-native. Most of the alien species occupied the riparian edge. However, a relatively high cover of alien English and German ivy occurred well within the forest. The forest was not included in quantitative sampling on the ground, because the forested area shows up well in aerial photographs of the site. One quantitative transect was located at the edge of the tidal lagoon in the lowest part of the riparian corridor, but not in a forested site. This site is similar to the low wet ground and ditches in the pasture area, which are all referred to as aquatic plant communities because they are submerged often. All the aquatic plant sites are discussed in a later section after the description of the drier pasture habitats (Figure IV-23).

- *Dry Pastures*

Most of the pastures are historic wetlands filled with as much as 6 feet of sediment soil. They are only partially covered by standing water during the rainy season. Of the 58 plant species recorded, 58% were aliens. These species were highly concentrated on the raised, flat, grazing land which characterized most of the pasture area. In contrast, native species were most abundant (in number and percent cover) in the two narrow ditches and cattail pond which exist year-round in the pastures (Figure IV-22). These wet pasture areas are considered in the next section on aquatic plants.

The raised, flat pasture land was dominated by the non-native white clover and several species of alien grasses (Figure IV-24). The most abundant grasses year-round were rabbit's-foot grass and Italian rye. However, in winter the cover of all plants decreased significantly, as indicated by the increase in bare ground during the February survey (Figure IV-24).

Three native species were encountered relatively frequently along the dry pasture transects (Figure IV-24), but rarely accounted for significant cover: Meadow barley, the aquatic knotgrass and coast clover. Another native, low barley, may have been introduced from the central California valley.

The type of vegetative cover was strongly correlated with proximity to horse trails and grazing. Transects 5, 6, and 8 were located in pasture areas with heavy grazing pressure (Figure IV-22). These transects were most clearly dominated by weedy species and contained large areas of bare ground during winter months. Winter die-off of annual grasses and die-back of clovers combined with continued grazing resulted in significant reduction of plant cover (Figure IV-24).

Transect 6 was the closest of all the transects to upland (Figure IV-22). It did not exhibit the strong seasonal exposure of bare soil (Figure IV-24), probably because of the occurrence of more perennial pasture grasses there, namely meadow foxtail, than at the other sites. Tarweed, a native, colonized lower upland areas and the upper part of the meadow. The tarweed expression may have been a response to the wet winter and was probably relatively unrelated to grazing, contrasted to the other tall plants-thistles, docks and pennyroyal. These tall weeds were not so abundant that they dominated the cover along pasture transects, but were visually conspicuous members of the plant community.

- *Aquatic Habitat*

Areas with standing water, either in channels or broad low regions, were considered to be aquatic habitat. These included man-made excavations which held or conducted water most or all of the year-round. The channels included the Redwood Creek itself, with transect 3 located at the mouth in an aquatic habitat, as well as 2 channels or ditches through the pasture. These ditches continue the drainage of Green Gulch Creek (Figure IV-22). The main shallow ponded area was at the extreme seaward end of pasture C, where transect 4 was located (Figure IV-22).

Alien species comprised 43% of the 54 species recorded along the aquatic transects. In lower Redwood Creek (transect 3), alien species were concentrated along the lower creek edges; the dominant cover here included ox-tongue, Kikuyu grass, creeping bent grass and pennyroyal. The non-native knotgrass covered much of the shallow water flats where transect 3 was established (Figure IV-23). The remainder of the transect was dominated by native aquatic cover. Three emergent plants were most common: three square rush, cattails, and species of bulrushes. Other native wetland species which grew along the transect area included water plantain, tall cyprus, monkey flower, and small red alders.

Transect 4 extended across the low wet region in pasture C, which was contiguous with the permanent cat-tail pond and had been part of the past creek course draining Green Gulch (Figure IV-22). The transect sampled a colony of emergent perennial wet-ground vegetation: spike rush (*Eleocharis*), Three-square (*Scirpus*) and knotgrass (Figure IV-23). The area remained flooded much longer than other pasture sites and could not be sampled in February 1993. At that time seasonal growth of the species had not begun. All three species were grazed and trampled (but not destroyed) by horses, producing bare ground. The only other species recorded along the transect were a few pasture weeds, common plantain and annual grasses.

Many of the same aquatic species occurred along the pasture ditches, which also contained standing water most of the year. No quantitative surveys were done here.

- *Salt Marsh*

The salt marsh habitat is between the parking lot, lower creek and hillside (Figure IV-22). It was bordered by encroaching Kikuyu grass on its north and west sides, grading into an apparent remnant of salt marsh on the northwest edge. Riparian forest species, mainly small alders and willows, were mixed with non-native weeds along the east edge of the marsh. The marsh was divided by a beach access trail, and also crisscrossed by several other smaller footpaths.

Vegetation cover was strongly dominated in all seasons by two native species, rush and silverweed (Figure IV-23). Two alien species (radish and bristly ox-tongue) were the next most dominant cover species within the marsh community per se. However, the encroaching Kikuyu grass has crept over a significant proportion of the total area degrading it from marsh to disturbed habitat. This and other alien species, including jubata grass and poison hemlock, cover significant area and comprise 57% of the total species recorded.

Two salt marsh species occurred in the marsh in very small patches (less than 1 m^2 each). A few Alkali heath plants grew along the sandy northwest edge of the marsh and a patch of jaumea grew along the east side of the path.

- *Disturbed Habitats*

Most of the former wetland habitats in the Big Lagoon area are disturbed by past or present human land use, particularly the pastures. The two small habitats described in this section are also highly disturbed by human activities. Although they are not large areas, they are likely restoration sites and may change radically in the future.

Transect 1 was located next to the parking lot (Figure IV-22), a site of heavy human use throughout this century. Kikuyu grass comprised nearly 100% cover along the transect, except during the spring when non-native vetch was a co-dominant (Figure IV-23). Kikuyu grass graded into salt marsh where rushes and silverweed became dominant (Figure IV-23: transect 2); into the urbanized upland dominated by weeds, and ornamental species; and into the parking lot/picnic area covered by herbaceous weeds such as annual grasses and scarlet pimpernel (Figure IV-22). The only native species observed were occasional rushes.

The creek levee or walking path is another area highly disturbed by human activities. No quantitative data were collected, because qualitative observations revealed a predictable plant assemblage dominated by non-natives weeds including Kikuyu grass, low annual grasses, thistles, poison hemlock, ox-tongue, mustard, radish and French broom.

The levee supported more native species along the riparian bank, especially alder, willow, nettles and thimbleberries. Native trees of unknown origin grew along the pasture side, including black cottonwoods, buckeyes, shore pine trees, and an elderberry.

■ *Discussion*

The existing plant communities indicate a highly disturbed wetland complex. The number of non-native and often invasive species is high, covering most of the pasture area and surrounding permanent human structures such as the parking lot, roads, and levee path. In the pasture, some of the non-native grasses were introduced or encouraged for grazing such as meadow foxtail an white clover. Other weedier species are adequate forage for grazing horses, such as Italian rye and Harding grass, but others, such as rabbit's foot grass and ripgut brome, are generally just considered pests.

The plant communities with the greatest native composition and cover were usually wetter, occupying the riparian and aquatic habitats. These plants are generally good colonists of wet ground. For example, red alders have expanded towards the mouth of Redwood Creek in recent years, forming a dense stand of young trees just inland of the tidal lagoon. This species also colonized and spread along the riparian corridor when cattle grazing was slowed and discontinued along the creek.

However, the wetlands are highly susceptible to invasion by alien plants as the landscape dries. The pasture community is an excellent and well known example. Many wetlands are ditched and drained to create pasture for grazing. The pattern is also present in the small salt marsh, where the dry years of the past decade probably diminished the health of rushes and silverweed, allowing alien weeds to become established and persist. Weed abundance was also undoubtedly stimulated by chronic disturbance from wandering dogs and people. If the past year is indicative of a return to wetter years, then many of the weeds may be drowned. Growth of silverweed in the summer of 1993 appeared more robust than the past year, perhaps a response to wetter conditions.

Some of the introduced species provide a major challenge to eliminate. None may be more difficult than Kikuyu grass. It was apparently introduced, or at least actively encouraged, when the park began to manage the area for visitor use presumably because of its lawn qualities, ease of maintenance and persistence. It is a perennial, the leaves brown seasonally, but build up heavy, suffocating cover. The grass grows in a large variety of habitats produces a deep, thick root system and is even difficult to kill with herbicides. Unfortunately, it is also not a preferred plant to grazing animals.

The plant communities are the major habitat for the faunal groups discussed in the next sections. The location of sampling for the different animal communities is usually different, because each prefers different subhabitats. Nevertheless, a similar general pattern emerges for the animal communities: aliens invade the dryer landscape more than the wetter regions where natives still dominate.

b. *Aquatic Invertebrates*

• *Freshwater Habitats*

Like the plants, aquatic insects were sampled both qualitatively and quantitatively. Qualitative surveys were made to provide a broader perspective on the spatial and temporal changes in the fauna, and especially to locate representative habitats for more intense quantitative sampling. The location of original survey sites (only sampled once), and seasonal qualitative and quantitative survey sites are shown in Figure IV-25. The details of sampling methods are provided in Appendix

B. Since amphibian larvae were captured while sampling for aquatic invertebrates, they became a secondary focus of the surveys.

The seasonal patterns in quantitative nocturnal traps were similar to those from the more qualitative daytime sweep samples. Sweep samples provide a good qualitative impression of species composition and relative abundance. Traps were set at two stations representing contrasting aquatic habitats, as indicated by sweep sampling. Station 14 is within a side channel of Redwood Creek and represents a quiet water pond in a fairly natural creek system (Figure IV-25). Station 15 is in the main pond within a large drainage ditch in pasture C (Figure IV-25: ditch 3).

- *Qualitative Surveys*

Late winter was a period of reduced abundance of aquatic invertebrates in Redwood Creek, coincident with a significant reduction in cover of emergent vegetation along the stream border after several episodes of flooding. There was a similar pattern in the pasture ponds, but less pronounced. In spite of the low numbers of insects, damsel fly larvae and water boatman nymphs were common at some sites, and ephemeroptera larvae were very diverse and common. Beetles, however, were scarce, although some larvae of predatory beetles were present. In all cases, the highest numbers of insects were collected at those sites with the highest vegetation cover.

Insect abundance and species richness were substantially higher by the spring sampling compared to the late winter. Most numerous were waterboat man nymphs and adults. Mayfly nymphs, beetle adults and larvae, backswimmer nymphs, fly larvae, giant waterbugs, and damsel fly larvae were also common. The insects were clearly more abundant and diverse than in early March, with more species and individuals found in the pasture ponds than in the river. This pattern was most likely due to the much greater cover of emergent vegetation in the ponds versus the stream. During the March sampling, the pasture ponds had been turned into mud holes by the horses, and had even less emergent vegetation than the stream. By May, however, sufficient forage was available in the dry pastures so that the horses were no longer trampling the marsh vegetation, which was lush and supported a rich insect assemblage. Thus, insect abundance and diversity were correlated, as during March, with vegetation cover.

With the onset of the summer dry season, standing water was much reduced in the pasture and marsh areas. Emergent vegetation was well developed in the remaining wet habitats, but still less abundant in Redwood Creek than at the pasture pond sites. Insect abundance was similar to the spring sampling, but with proportionately more adults, and fewer juvenile and larval stages than in May. This pattern was especially true for the beetles, backswimmers, and water boatmen. Giant water bugs, mayfly nymphs, and damsel fly larvae, were all less common in July than during the spring, and damsel fly larvae were still generally found only in Redwood Creek net samples. Diptera larvae, however, were more abundant and diverse than in May at all sites. These larvae were especially common in Redwood Creek.

The largest individuals, and the highest densities were found in the remains of the temporary pond among the cattail stand at the extreme southwest end of the pasture (Figure IV-25: station 2, square symbol). Here, not only was the insect fauna well developed and mature, but this was also the only site where amphibian larvae (Pseudacris and the California newt) were taken. Interestingly, there were no adult or larval beetles (predacious or otherwise) taken at this site.

Planktonic crustaceans (amphipods, daphnia, and copepods) were generally more abundant in the pasture ponds than in Redwood Creek.

- *Quantitative Surveys*

Total insect abundance was highest during the spring at the pasture ditch, with species dominated by members of the order Hemiptera, primarily juvenile water boatmen (Figure IV-26). Beetles (*Coleoptera*) and mayfly larvae (*Ephemeroptera*) were also more abundant at the this site during the spring sampling period (Figures IV-26). Odonata (damsel fly and dragon fly) larvae and fly (*Diptera*) larvae, however, became more abundant during the summer at the creek station.

Crustacean abundance in the pasture ditch was highest during the late winter, and steadily decreased toward summer (Figure IV-27). This group was made up primarily of amphipods, copepods, daphnia, and ostracods. Copepods were the most abundant crustaceans throughout the year, with ostracods achieving comparable numbers only during the late winter (Figure IV-27). Amphipods, were generally rare, with none present in the traps during the late winter.

Both the insect and the crustacean fauna were generally less abundant and diverse at the Redwood Creek site than at the pasture ditch or pond (Figures IV-26 & IV-27). This pattern was particularly evident during the late winter, when no insects or crustaceans were found in the Redwood Creek nocturnal traps. As at the pasture site, summer abundance was generally the same or lower than during the spring. Interestingly, the only insects found in substantially greater abundance in the creek were fly larvae, particularly mosquitoes and chironomids (Figures IV-26 & IV-27).

Two species of amphibian larvae were collected during the insect surveys, Pacific treefrogs (*Pseudacris regilla*) and California newts (*Taricha torosa*). These were only trapped at the pond site during the late winter and spring surveys, and never in the Redwood Creek traps (Figure IV-28).

■ *Discussion*

The results from the seasonal aquatic insect survey indicate that expanding the extent and year round duration of ponded fresh water and associated aquatic vegetation will significantly increase the numbers, diversity, and persistence of insects, crustaceans, and amphibians found at Muir Beach (see Table IV-7). At least three factors likely contribute to the general pattern of lower diversity and abundance in the creek compared to the pasture ponds. Winter flooding of Redwood Creek tends to flush out the insect and crustacean fauna along with much of the emergent aquatic vegetation with which these species associate. This pattern was most dramatic during the late winter and spring surveys in 1993, when insects, crustaceans, amphibians, and vegetation were still abundant in the pasture ditches, but greatly reduced at the Redwood Creek sites (Figures IV-26 – IV-28). Abundance of these species did not begin to increase in the creek until spring and summer, if at all.

A major factor limiting the abundance and duration of aquatic fauna and vegetation at the pasture sites is the combined action of seasonal drying and disturbance from grazing horses. As the ponds and areas of standing water associated with the drainage ditches begin to shrink with the onset of the summer dry period, the horses gain access to these habitats. This disturbance results in the trampling and destruction of emergent vegetation well before the natural drying cycle of the ditches, and was evident during the September 1992 survey. The combined desiccation and trampling apparently leads to the decline in pasture invertebrate communities at the beginning of summer in contrast to the persistence of many of these species in Redwood Creek during the same time period. Redwood Creek, unlike the horse pasture ditches, has a year round water source, and is not subject to horse grazing disturbance. Creation of a larger pond, with a more reliable water source will greatly reduce the effect of horse related disturbance.

The final factor influencing these patterns may be the relative absence of higher tropic levels in the ditches (i.e. larger predaceous fish) and therefore the greater numbers of predaceous insects (beetles, water boatmen, backswimmers, odonota larvae) and amphibian larvae in the pasture ponds and ditches compared to Redwood Creek. These differences likely contribute to the higher numbers of crustaceans and lower number of mosquitoes and other dipteran larvae in the ditches versus Redwood Creek. This later result will be of particular interest to those concerned that increasing ponded water at Muir Beach will enhance mosquito production. This evidence suggests that the Redwood Creek backwaters, not the pasture ponds promote mosquito growth.

- *Tidal Lagoon*

The tidal lagoon fauna was sampled to detect potentially important prey for creek fishes, and to determine if this brackish invertebrate community was well developed in the lower creek. Benthic invertebrates were sampled at three stations in the tidal lagoon (Figure IV-25) using simple core samples pushed into the sandy substrate (see Appendix B for sampling methods). Aquatic insect larvae (a fly larva) were the most abundant animals in the lagoon sediment (Figure IV-29). Annelid worms, both oligochaetes and polychaetes (mostly nereids), were next in abundance. Preliminary qualitative surveys of the tidal lagoon the previous summer also revealed annelid worms and amphipod crustaceans, but not dense populations and only in quite limited habitat areas. The large number of oligochaetes at one station in March may have been a real seasonal pattern or a local patch sampled from a slightly deeper part of the lagoon bottom. The pericarid crustaceans, the amphipod *Corophium* and the cumacean *Leucon*, are common in estuarine systems at river mouths. Although they can be important food for young steelhead in other systems, their local population densities were low and the total area of tidal lagoon is too small for these groups to be major fish prey in Redwood Creek.

c. *Amphibians*

Amphibian surveys at Big Lagoon were focused to concentrate on key amphibian habitats. These included locations where surface water was present as well as the creeks and riparian zones. Species composition and relative abundance were estimated in qualitative surveys made each month and more frequently during wet periods when wetland usage was greater (see Appendix B for survey methods). Eight native amphibian species were found during surveys from April 1992 to September 1993 (Table III-1). No non-native species (most importantly, no bullfrogs) were observed, although extensive surveys were conducted up Redwood Creek and the ponds at the Green Gulch Farm.

By far, California newts were the most abundant adult individuals observed. Their numbers peaked with breeding concentrations in January, but individuals were present throughout the year (Figures IV-31 and IV-32). Spawning occurred from December to February.

Aside from California Newts, adult amphibian species occurred in low numbers year-round (Figure IV-30), but many species were consistently present (Figure IV-31). Adult Pacific tree frogs were seen or heard from December through May. The ensatina and slender salamander (*Batrachoseps attenuatus*) were occasionally encountered on the margins of wetland habitat in the winter and spring months (Figures IV-31 & IV-32). The red-legged frog was observed on at least two occasions during spring. As it is a federal candidate species, it is discussed in the Special Status Section.

Larval stages of four amphibian species also occurred at Big Lagoon (Figure IV-31). California newts and Pacific tree frogs were most abundant. With the prolonged rains this year, California newt larvae were found into October (Figure IV-33) and Pacific Tree Frog larvae were found April through July in suitable localized breeding areas at Stations 1, 3, 6 and 7 (Figure IV-30). Two other species, the western toad and rough-skin newt, were found in much lower numbers and only in larval stages.

■ ***Discussion***

Amphibians are among the most sensitive and threatened vertebrate species in California freshwater wetland systems (Moyle 1973; Jennings and Hayes 1985; Hayes and Jennings 1986; Jennings 1991). In recent years they have been indicators of global environmental conditions (Phillips 1990; Cowan 1991) and habitat destruction (Jennings and Hayes 1985, Pechmann *et al.*, 1991). Most amphibians are closely tied to an aquatic environment due to their aquatic larval stage. In Big Lagoon, this is the case with all amphibian species documented at seven ponded or channeled areas. These standing water locations are essential to the viability of the amphibian assemblage at Big Lagoon. It is in these localized wet spots that wetland vegetation provides necessary cover for reproductive activities and a basis for amphibian prey species. The current complement of amphibians at Big Lagoon both in terms of numbers and species no doubt reflects the marginal size and health of available wetland habitat (Table III-1).

The existence of a large Pacific tree frog larval population probably reflected the above-average rainfall this year which provided suitable breeding habitat in drainages until at least mid-July (Figure IV-33). Additionally, insect surveys indicated appropriate prey were available to developing frog and newt larvae in the ponded sites (see Aquatic Insect section). Pacific tree frogs are closely tied to the water throughout their life history, though they require standing water only for chorus, breeding, spawning and a short 3-month tadpole stage. This species is thus able to breed successfully in the pasture ponds.

Ensatina, slender salamander and arboreal salamander are terrestrial species without larval stages which occupy upland habitats. Generally, they are solitary and secretive and not readily seen except under logs, vegetative litter, or rocks after rains drive them up from underground burrows. The arboreal salamander is less tied to water than the others. It resides and lays eggs underground, in tree cavities, or otherwise moist shelters such as beneath logs. The first fall or winter rains bring them to the surface where they remain active until the rains stop (Stebbins 1954).

Only two species which have previously occurred in this region according to museum records were not found during surveys: the Pacific giant salamander (*Dicamptondon ensatus*) and the yellow-legged frog (Table III-1). The Pacific giant salamander occurs primarily in humid well-forested areas (Stebbins 1954), and the yellow-legged frog lives in riffled streams with at least cobble-sized substrate (Hayes and Jennings 1989). As neither habitat type occurs within the survey area, it is not surprising that these species were not observed, although both are known from farther up Redwood Creek in Muir Woods.

Though bullfrogs were not documented in this study, and have also not been seen by Green Gulch Farm personnel (personal communication), they are common in the nearby Tennessee Valley and could conceivably enter Big Lagoon. This invasive species eats young pond turtles and it is suspected that they will eat red and yellow-legged frogs as well (Hayes and Jennings 1986). Yellow-legged frogs and pond turtles are federal candidate species and red-legged frogs are federal proposed species. Bullfrogs indicate a modified pond habitat which is less suitable for native species.

d. *Reptiles*

Three reptile species were observed during amphibian surveys at Big Lagoon: the western pond turtle, western fence lizard (*Sceloporus occidentalis*), and the western terrestrial garter snake (*Thamnophis elegans*) (Table III-1). Two other species were observed during three additional qualitative reptile surveys: the northern alligator lizard (*Elgaria coeruleus*) and the western aquatic garter snake (*Thamnophis couchi aquaticus*).

At Big Lagoon the western fence lizard occurred as an upland resident, and the coast garter snake patrolled upland as well as wetland and riparian habitats for prey. While garter snakes were less common in the afternoon amphibian surveys (Figure IV-30), they were seen in substantial numbers during the qualitative reptile surveys.

Less than half of the 12 reptile species historically occurring in this region (Table III-1) were observed during our surveys. However many of the reptiles not seen are more upland inhabitants preferring drier sites or open areas at the margins of forests. This is especially the case for the western skink (*Eumeces skiltonianus*), Southern alligator lizards (*Elgaria multicarinata*), and the yellow-bellied racer (*Coluber constrictor*). The upland and drier sites probably support substantial populations of lizards and snakes (Ed Ely, pers. comm.), but these areas were not part of the regular survey area.

A few reptile species which were not observed in this study but have historically occurred here, are known to forage in wetland areas (ring-necked and sharp-tailed snakes) or in pools and along stream banks (rubber boa). Increasing the size and quality of these habitats should make these species a more visible component of the Big Lagoon fauna.

e. *Birds*

Bird surveys were conducted at permanent stations in Big Lagoon (Figure IV-34) to measure current seasonal use of a range of habitats potentially affected by future restoration efforts. Standardized counts were repeated in all seasons at 15 stations (Table IV-8; see Appendix B for Methods and station modifications during survey period). Variation in both individual and species numbers between surveys is high and sample sizes are relatively low after one year of sampling a fauna which is known to vary greatly in space and time. In addition to comparisons of seasonal and habitat use, a species list was generated from survey data and incidental sightings; however, it was intentionally not made the primary focus of the field work. It should therefore be considered supplementary to more comprehensive lists compiled specifically for that purpose. All species names used in text and figures are accepted common names established by the American Ornithologists' Union (1983,1985).

Eleven standard bird surveys were conducted during the first annual survey period, 29 May 1992—9 August 1993. During this period, 1603 individuals comprising 67 bird species were recorded. An additional 33 species were incidentally observed outside station boundaries or on non-survey days (Table IV-9) between 29 May 1992 and 31 October 1993. All 100 species were grouped according to known feeding associations with terrestrial or aquatic prey (Table IV-9; National Geographic Society 1983, Shuford 1993, Small 1974). Most species observed at Big Lagoon (61%) were terrestrial associates, species which fed on terrestrial vertebrates, vegetation or associated insects or aerial insects. Of these terrestrial species, nearly all (93%) breed in Marin County (Shuford 1993) and most (77%) are year-round county residents. Brewer's Blackbirds, Red-winged Blackbirds and Pine Siskins were the most abundant terrestrial species counted during surveys; all are year-round residents. Three species of swallows (Tree, Barn and Rough-winged) comprised the most abundant summer resident species.

Wetland associates comprised the remaining 39% of species observed at Big Lagoon (Table IV-9). About half of these wetland species (49%) occur in Marin County year-round (Shuford 1993); this includes the Mallard, Killdeer and Great Blue Heron, which were the most abundant wetland individuals recorded. The remaining wetland species (51%) are winter resident/non-breeders (Shuford *et al.* 1989), overwhelmingly dominated by winter feeding flocks of American Widgeons.

Total numbers of individuals and species observed at Big Lagoon stations varied greatly during the sampling period (Figure IV-35). In particular, individual abundance was highest during late fall and winter. Note that the high November individual total is partly due to a single flock of 200 small unidentified passerines (probably finches) flying overhead, though omitting this sighting does not change the general trends shown in the Figure IV-35. The January 1993 counts would have been much higher if weather permitted a complete survey of all stations. However, due to inclement weather, the survey included only the 3 pasture stations and an additional 1-time count of station 14 (see Appendix B for Methods and station changes). At the time, station 13 was submerged by about 1/2m water and over 100 waterfowl (primarily American Widgeons) were feeding and resting along the edge of the temporary pond where station 14 was established.

The numbers of individuals and species which occurred within individual stations varied according to habitat type (Table IV-10). Stations which encompassed riparian corridors (i.e. Riparian Footpath, Redwood Creek, Riparian Vegetation, and Dense Willows Stations) generally supported higher average numbers of species and individuals per area than stations characterized by low vegetative cover and relatively high human disturbance (i.e. Pastures, Kikuyu grass Meadow and Lagoon). Within the riparian areas, it appears that those including water channels (Riparian Footpath and Redwood Creek stations) actually supported slightly fewer species and individuals than those without channels but with dense vegetation (Riparian Vegetation and Dense Willows Stations). However, note that the channel stations are also closest to the most-used pathways (Figure IV-34). The very high number of individuals observed in the Kikuyu meadow were due to a single flock of

200 small passerines flying overhead. Omitting this sighting greatly reduces this station's apparent high rank in avifaunal use.

The average numbers of birds observed during surveys of the three riparian stations bordering the footpath and the three pasture stations were grouped by season (i.e. spring/summer = March-June; fall = July-October; winter = November-February) to assess general trends in occurrence of migrants as well as summer and winter residents (Figures IV-36). Wetland associate species, primarily waterfowl, were most common during winter in flooded pasture stations, comprising 34% of individuals and 46% of species observed. Wetland birds were less common in the riparian footpath stations than the pasture stations at all seasons (Figure IV-36), and were represented primarily by herons and nesting mallards. In both station types, the fall season was generally low in total numbers and particularly wetland bird numbers, apparently reflecting a transition period between breeding activity and the appearance of winter residents. Figure IV-36 presents numbers of individuals per survey, not per m^2; therefore any comparison of relative abundances between station types should take into account that the Riparian Footpath stations are less than 1/4 the size of pasture stations (Table IV-9: $600m^2$ vs. $2500\ m^2$).

Average numbers of birds at the two Redwood Creek stations and the two Riparian Vegetation stations were similarly grouped by season and proportion of wetland species (Figure IV-37). Not surprisingly, wetland species occurred only in the creek stations. The total numbers of terrestrial individuals and species was noticeably higher in the vegetation stations than the creek stations, despite the smaller size of the former (Table IV-10: $250m^2$ vs. $450m^2$ creek stations). Note that the riparian vegetation stations, in addition to being subjected to relatively low levels of human disturbance compared to the road-front creek stations, also encompassed a greater variety and density of vegetative cover. The Riparian Vegetation stations were consistently occupied by a variety of small resident passerines including Chestnut-backed Chickadees, Pine Siskins, Song Sparrows and House Finches.

During the 1¼-year survey period, thirteen bird species were observed nesting or exhibiting breeding behavior at or near Big Lagoon (Table IV-11). This includes nine species and one subspecies within Big Lagoon and an additional three nesting species nearby. Two are particularly noteworthy: the Peregrine Falcon and salt marsh subspecies of the Common yellowthroat. The Peregrine Falcon is state and federally endangered; a Peregrine Falcon pair nested successfully in 1992 at the "overlook" cliff site immediately north of Muir Beach (Onorato pers. comm.); Peregrines have also successfully nested on cliffs just south of Muir Beach in previous years (GGNRA rangers, pers. comm). The Salt Marsh Common Yellowthroat is a Federal Candidate 2 and State Species of Special Concern. A pair was observed in a coyote bush at the boundary of the Kikuyu meadow station (near the lowest section of Redwood Creek) on 9 August 93. They may have nested in or near Big Lagoon. All of the remaining nesting species observed in Big Lagoon chose nest sites in available vegetation near the creek, drainage channels or the remnant marsh in the southernmost pasture.

- *Discussion*

The bird surveys and incidental sightings recorded during 1992-1993 documented a predictable assemblage of coastal riparian and wetland birds which varies seasonally according to the breeding and wintering habits of each species. Big Lagoon harbors bird species which are members of several wetland communities, including freshwater marsh, freshwater stream, coastal riparian forest, and more restricted brackish marsh and coastal dune communities (Shuford 1993). As discussed in the Historical Conditions section, all are remnants of what were once large expanses of coastal wetlands and watersheds. Current numbers of species and individuals are undoubtedly a fraction of what this system supported 200 years ago, prior to human-induced filling of stream corridors and wetlands, decreases in freshwater input, severe habitat fragmentation, replacement of native wetland and upland vegetation with non-native pasture vegetation, and ongoing disturbance by human visitors and pets. Enhancing the quality and size of wetland habitat, in lieu of pastures which currently support few bird species or individuals, should significantly increase the diversity and abundance of native birds in Big Lagoon.

f. *Mammals*

Though no mammalian surveys were conducted at Big Lagoon, three species were incidentally noted in the Big Lagoon region during 1992-93 field work (O. Onorato, P. Slattery pers. obs.). Mule deer tracks were observed in the dense willow thicket between bird stations 5 and 10 in spring 1993, and occur here relatively commonly. Both bobcats and gray foxes were seen infrequently along the riparian corridor. Gray foxes regularly use the dense willow thicket as a denning area. Though not recorded, other likely inhabitants include raccoons, wood rats, deer mice and other small mammals. Table III-2 lists all the small and large mammals that might live in or have lived in and around the Big Lagoon wetlands and that should periodically use a large freshwater wetland for at least food or water.

2. <u>Non-wetland Habitats (Dunes and Hillsides)</u>

a. *Dunes*

The dune community at Big Lagoon occupied the narrow fringe between the intertidal zone and the lower creek channel (Figure IV-22). Only in the southeast corner was there sufficient space for vegetation to escape winter storm waves. Three tiers of dunes were semi-quantitatively sampled: 4 low mounds above the high intertidal zone, 2 large back dunes footing the upland hillside, and 2 larger mounds intermediate between the first two tiers (Figure IV-22: all within dune area).

Sixteen species of plants were observed on dune habitat. Only three true dune species occurred: beach bur, native dune grass and sand verbena. An additional coastal native species, lizard tail, was found in the backdune. However, it is not restricted to dunes, but is common in coastal scrub communities. Seven alien species grew in the dune habitat, including the highly competitive European dune grass, ripgut brome and Hottentot fig (ice plant). One alien, sea rocket, is actually considered a favorable early colonizer of the lowest, wave- and wind-disturbed foredunes. The other aliens were typical of upland habitat and were not abundant.

The low count of native dune species was indicative of the degraded state of the habitat. Though the narrow area available between foredune and hillside restricted development of mid- or backdune plant communities, the most important inhibitor to the establishment of a healthy dune community was overuse by visitors. Trampling killed plants, destabilized sands, and thus precluded re-establishment of native vegetation. The foredunes were more species-poor and had lower vegetative cover than healthy dune communities in other coastal areas, such as the better developed local dunes at Stinson Beach. Species present included both natives (beach bur) and highly invasive non-native species (ripgut brome and European dune grass). Middunes were also vegetated by natives (e.g. beach bur, dune grass) and non-natives (Kikuyu grass). Back dunes graded into the hillside and supported moderate to dense cover of natives (mugwort, sand verbena and native dune grass) mixed with a significant cover of non-natives like ripgut brome and mustard.

Natural disturbance of the dunes by wave wash may have almost as much impact on dune vegetation as human disturbance. Winter storms commonly wash most of the central and northern section of the beach, with sea water running into the tidal lagoon. This disturbance occurred during several high tides and winter storms this year.

The beach habitat was not quantitatively surveyed for any animals due to the high incidence of human and dog disturbance. Qualitative surveys of birds consisted merely of a quick scan of the beach from a dune during regular survey dates to determine composition and approximate abundance of species on the sand and bordering rocky boundaries. Ten bird species were observed, including 3 special status species (Brown Pelican, California Gull, Black Oystercatcher; see Special Status section). The beach would undoubtedly be used as a roosting and foraging area by much larger flocks of several shorebird and seabird species if undisturbed.

b. *Upland Hillsides*

One plant transect was regularly surveyed along the hillside coastal scrub community (Figure IV-22: transect 9). The site was dominated by the cover of alien annual species (Figure IV-39). Common aliens included hair grass, soft chess, geranium, annual fescues, hedge hog dog tail, and plantain. These non-natives comprised about 50% of cover over time. needle grass, blue wild rye and yarrow were the most common natives recorded. The variation in cover was not clearly linked to seasonal changes but more to small scale habitat complexity involving many species and many plant sizes.

Aside from the single upland transect station, only a broad qualitative assessment was made of the uplands near Big Lagoon, and no attempt was made to generate a comprehensive species list. However, 52 plant species were recorded along or near the transect, a large number considering the small area sampled. About one half of them were alien.

A nearly 150-year history of cattle grazing was probably responsible for the high proportion of alien plant cover. In addition to aliens recorded on the transect, dense thickets of Harding grass, thistles and poison hemlock grew in swales where cattle had likely congregated in the past. Many smaller, short-lived aliens were numerous and indicative of heavy grazing disturbance.

Recent photos (1991) document some recovery from livestock disturbance. The hillside grassland of non-natives is apparently being replaced in some areas by native shrubs, probably mostly coyote brush. Native herbaceous species, including perennial grasses such as needle grass and blue wildrye, are present. However, the abundance of alien species in both quantitative and qualitative observations indicate that the uplands are still significantly damaged from past disturbances.

The upland habitats adjacent to the Big Lagoon wetland should support substantial populations of lizards and snakes (Ed Ely, pers. comm.). The Western fence lizard, alligator lizard, and the coast garter snake were the only species seen on amphibian surveys but many other species are expected to occur including skinks, yellow-bellied racers and possibly most of the reptile species historically present in Marin County (Table III-1). Small rodents and insects living in the grass and leaf litter undoubtedly support these species as prey. The ensatina, slender salamander, and Arboreal salamander also occupy the upland habitats as well as the margins of wetlands.

Very few birds were observed in the single hillside upland station (Station 30; Figure IV-34) surveyed 29 May to 25 November 1992 (Tables IV-7 & IV-9). During five surveys, a total of 4 species (Brewer's Blackbird, Bewick's Wren, Golden-crowned Sparrow, Killdeer) and 5 individuals were observed. All were predictable residents or visitors of coastal scrub habitat. Though not observed, other likely visitors include raptor species such as Northern Harrier, Red-tailed Hawk and Great Horned Owl as well as several passerine species such as California Quail, Bushtits, Rufous-sided Towhees and White-crowned Sparrows. This upland station was abandoned after November 1992 in favor of increased coverage of lowland habitats which were more likely to be impacted by restoration efforts.

3. Fisheries

a. *Redwood Creek, Upstream of the Beach Area*

Four stream sites, from the first bridge upstream of the beach upstream to Muir Woods National Monument, were sampled by backpack electroshocker in both 1992 and 1993 (Table IV-12). In 1992 coho outnumbered steelhead in summer sampling at all four sites. In 1993 coho densities were similar to those of 1992, but steelhead densities substantially increased (Table IV-12).

At Muir Woods, very high densities (84 to 91 fish per 100 feet) of coho were present in both 1992 and 1993, and in 1992 coho outnumbered steelhead by over 3 to 1 (Table IV-12). The high fish densities and dominance by coho reflect good pool and cover development and excellent substrate conditions. Riffle sculpin were also abundant at the site, and some prickly sculpin were also present.

Upstream of the third bridge upstream on Redwood Creek, within Tamalpais State Park, fish densities were substantially less than at Muir Woods in both years (Table IV-12), despite good pool and cover development and substrate conditions. The site is very heavily shaded (99% canopy), and fish production may be limited by food availability. Threespine stickleback, prickly sculpin and riffle sculpin were also collected.

Downstream of the agricultural and domestic diversions, Redwood Creek was reduced to isolated pools in 1992, although flows upstream of the diversion remained above 0.2 - 0.25 cfs. Dissolved oxygen levels were as low as 2.5 mg/l in some of the isolated pools, and coho density dropped by two-thirds between September and November sampling (Table IV-12). Total fish density at the end of the summer was probably less than 20% of that of the site upstream of the diversion, and less than 16% of the next site downstream, where summer flows dropped to only 0.01 cfs (Table IV-12). In 1993 streamflows were maintained at the site and total coho and steelhead density was 9 times that of 1992 (Table IV-12). In 1993 most of the fish present were steelhead. Threespine stickleback and some prickly sculpin and riffle sculpin were also collected. Substrate at the site includes more sand and finer gravel than upstream, but suitable coho and steelhead spawning sites are present. Pool development is also less than at upstream sites, possibly partly due to bank modifications.

At the first bridge upstream of the beach, streamflows declined to only about 0.01 cfs in late summer 1992. Salmonid densities declined by almost 40% between July and November (Table IV-12), apparently due to the loss of shallow run and riffle habitat for rearing. In 1993 collected coho were less abundant than in 1992, reducing total coho and steelhead density compared to 1992 (Table IV-12). Part of the observed difference was due to inability in 1993 to sample a pool that in 1992 had both high fish densities and a high proportion of coho. Threespine stickleback and some prickly and coastrange sculpin were also collected at the site. Although the site has primarily fine gravel and sand substrate, some suitable steelhead and coho spawning sites are present.

b. *Redwood Creek, Pools Near Parking Lot*

Immediately upstream of the lagoon, a depositional delta, gabion bank protection, channel realignment and levee construction combine to produce a long, deep on-channel pool and a back-water channel behind the creek levee. Depth of the on-channel pool is up to 1.2 m and depth of the back-water channel is up to 1.6 m. Neither habitat is well-shaded, resulting in growth of abundant algae and rooted and floating aquatic plants. In addition, since the back-water channel is not scoured by winter flows, organic detritus up to 0.2 m thick accumulates on the bottom. Detrital algae, cattails and riparian leaves also accumulate in summer in the on-channel pool.

The highest water temperatures in 1992 and 1993 briefly exceeded 20°C near the surface in late afternoon, but cooled off substantially (15-18°) over night and during overcast periods. However, because of algal growth and detrital decomposition, the pools experienced low summer dissolved oxygen levels in morning and during cloudy periods (Table IV-13). During 19 September 1992 sampling, the dissolved oxygen levels ranged between 2.0 and 4.3 mg/l in the morning (Table IV-13 and Appendix C), and because of overcast, they increased little from photosynthesis during the day. Juvenile steelhead were observed in the morning gulping at the surface to force more highly oxygenated boundary water over their gills. At the time, there was no surface inflow from Redwood Creek to the pools. Even in 1993, when surface inflows were present, morning dissolved oxygen levels were mostly below 6.0 mg/l during August and September sampling (Table IV-13). Near the foot bridge at the tail of the large on-channel pool, dissolved oxygen levels near the bottom were often very low, even in the afternoon. Bottom disturbance by swimming dogs was usually responsible; most unleashed dogs crossing the bridge jumped in the water for a swim, and on one afternoon 4 dogs were counted splashing in the water within 15 minutes.

In 1992 and 1993 both coho and steelhead were abundant in the pools in early summer (Table IV-12). Not only were numerous fish caught by relatively inefficient deepwater electroshocking, but schools of coho and steelhead were regularly seen. In 1992, however, both species disappeared over the summer, presumably due to poor dissolved oxygen levels. In 1993 coho and steelhead also declined substantially over the summer, but some fish were still present in September (Table IV-12). The primary present value of the pools for coho and steelhead is probably as feeding and resting areas in winter and spring for outmigrating smolts.

Threespine stickleback and prickly sculpin were common in the pools throughout the year. In both 1992 and 1993 yellowfin goby were also commonly collected. All gobies exceeded 80 mm standard length (adult size), so it is not known whether a reproducing population is established in the lagoon.

In 1992 juvenile Sacramento blackfish were present in the pools and in 1993 two Sacramento perch were collected. Both species are present in a pond in Green Gulch, and occasional individuals probably enter Redwood Creek with pond overflow.

c. *Intermittently Tidal Lagoon*

The intermittently tidal lagoon at Muir Beach is relatively small, and its size and depth varied substantially with sand bar formation and streamflow. In 1992 the sand bar was closed by 23 June and the deepest part of the lagoon was probably about 1.25 (Table IV-14). However, streamflows declined over the summer, and by 19 September there was no inflow and maximum lagoon depth had dropped to only 0.65 m. On 23 June, with a recently closed sand bar and good streamflow, the lagoon was mostly freshwater (0.6 ppt salinity), except for a thin layer of more brackish water on the bottom (Table IV-14). In August and September the shallow, wind-mixed lagoon was brackish and unstratified. The sand bar was by breached by a late September storm, but re-formed; in November the lagoon was again deeper, very salty and stratified (Table IV-14).

In 1993 the lagoon was open, shallow and stratified on 4 June (Table IV-14). Runoff from a heavy storm on that day lowered the partial sand bar. On 9 June and 24 June the lagoon was shallow and draining at the time of sampling; during that part of the tidal cycle the lagoon was freshwater. On 19 August the sand bar was in place, and the lagoon was relatively deep (1.2 m) and stratified (Table IV-14). By September low streamflows had reduced the lagoon to a shallow (0.65 m), unstratified, freshwater pool. Inflows in excess of 1/2 cfs are probably needed to keep the summer lagoon over 1.2 m deep and to back water into the adjoining salt marsh.

Because of wind mixing, dissolved oxygen levels in the lagoon were generally good in 1992 and 1993. However, when detrital kelp was present (14 November 1992) and during prolonged calm, overcast periods (10 September 1993) dissolved oxygen levels were lower. However, because the lagoon was shallow and unshaded, afternoon water temperatures were often quite high (Table IV-15). On 23 June 1992 early evening water temperatures throughout the water column reached 23.5° C (75°F). When the lagoon was stratified for salinity, the highest water temperatures were within the salt water lens near the bottom (19 August 1993) (Table IV-15).

Threespine stickleback were always abundant in the lagoon (Table IV-16). In 1992 juvenile steelhead were common in the lagoon in August (Table IV-16), despite the high afternoon water temperatures. Coho require cooler water, and none were collected in 1992. In 1993 both coho and steelhead were present on 4 June, but the storm on that day apparently flushed them from the shallow lagoon; none were seen in the lagoon during the remainder of the summer. In 1992 juvenile striped bass (to 7 inches long) were abundant in the lagoon. Other fishes collected in the lagoon in 1992 and 1993 were staghorn sculpin, starry flounder, and yellowfin goby (Table IV-16).

No tidewater goby were collected in either 1992 or 1993. Tidewater goby tolerate a wide range of salinity, dissolved oxygen and temperature conditions and lagoon sizes, but require lagoons with some refuge from the high currents of winter floods. The Redwood Creek estuary/lagoon presently has no backwater channels or salt marsh potholes to serve as winter refuges for gobies.

4. Special Status Species

a. *Vegetation*

No endangered, threatened or special species of plants were observed on the site (Figure IV-38). None would necessarily be expected in view of the tremendous changes to the site. A large number of listed plants may be found in the coastal scrub community adjacent to Big Lagoon (Smith and Berg 1988). More important to this study, several special species recognized by the California Native Plant Society (Smith and Berg 1988) occur in lowland habitats in Marin County and could have occurred in Big Lagoon historically (Table IV-17). For example, California bottlebrush grass occurs upstream in Muir Woods. Species in Table IV-17 could have occurred in Big Lagoon historically and may be considered for reintroduction as a conservation effort during restoration.

b. *Amphibians and Reptiles*

Herpetological surveys documented that the Big Lagoon wetland system currently supports at least two special status species: the red-legged frog and western pond turtle. These federal proposed and candidate species, respectively, warrant special consideration in the development of a restoration alternative.

Two confirmed sightings and one probable sighting were made of individual adult red-legged frogs at two locations (Stations 1 and 5; Figures IV-30 & IV-38) on April 29 and June 10. Both locations were densely vegetated by abundant cattails, a preferred emergent vegetation type. No larvae were observed, though special care was taken to detect this species. Therefore, it is unknown where adults spawn and if reproduction is occurring at Big Lagoon.

Red-legged frogs may be particularly intolerant of bullfrog invasions (Moyle 1973, Hayes and Jennings 1986). It is not clear if bullfrogs are the sole factor or more likely, if habitat alteration coupled with predation and competition by bullfrogs cumulatively have caused extensive red-legged frog declines throughout California (Moyle 1973, Hayes and Jennings 1986). Bullfrog range has expanded since their introduction to California in 1896 (Heard 1904 in Hayes and Jennings 1986), while the range of the red-legged frog has diminished by at least two-thirds. In the lower central valley red-legged frogs are extirpated from over 99% of their former range (Jennings and Hayes 1985).

The yellow-legged frog was not observed at Big Lagoon. Suitable habitat is present, however, on the stretch of Redwood Creek just past the bridge on Pacific Way (E. Ely, pers. comm.), and it is probable that they are sporadic residents.

Western pond turtles were seen throughout the year only in two locations along the dredged portion of Redwood Creek (Figure IV-30). While as many as three individuals have been reported simultaneously, most sightings were of solitary animals. The lack of juveniles and the low number of adults potentially is a bias of the visual survey method. It is important in determining their population status to locate juvenile animals and determine if reproduction is occurring and to accurately count adults by marking them. The one adult that was captured had growth rings indicating it was 15 years old. There is one recent unconfirmed sighting of a small turtle in Redwood Creek by the bridge.

A problem in even estimating adult presence is that animals move up and down the stream course or wander overland up to 0.5 km from water in search of suitable nesting sites (Rathbun *et al.* 1991). During periods of drought or floods, turtles may move into the chaparral or uplands burying themselves in the leaf litter and undergo a period of dormancy (B. Bury, G. Rathbun, pers. comm.). Animals in their migrations or during dormancy would not be counted in visual surveys, particularly from a single survey year. The best way to ascertain juvenile occurrence is through the use of baited traps set semi-submerged in the water near riparian vegetation. Young turtles could be upstream in Redwood Creek in smaller pools and shallower water (B. Bury, pers. comm.).

Today pond turtle reproduction at Big Lagoon is risky due to the lack of protected nest sites, lack of migration corridors to suitable nest sites, vulnerability of females during nesting, and vulnerability of hatchlings at the nest and during their first migration to water. While pond turtles are hard to catch in the water, when animals are moving about on the ground they are especially vulnerable to collection and harassment by humans, as well as attacks by dogs.

Two special status snakes, the endangered San Francisco garter snake (*Thamnophis sirtalis tetrataenia*, a subspecies of the common garter snake) and the State threatened giant garter snake (*Thamnophis couchi gigas*), a subspecies of the Western Aquatic garter snake, occur farther to the south and east, and are not expected at Redwood Creek.

c. *Birds*

Twenty-two bird species observed at Big Lagoon are currently designated by national, state and local entities as species of special status due to low population numbers, declining habitats, and/or highly restricted breeding areas (Table IV-11, Figure IV-38). Given the drastic reduction in wetland habitats which has occurred in California and the U.S. during the past 150 years, it is not surprising that 60% of the sensitive species which were observed at Big Lagoon utilize riparian and marsh habitats for breeding, feeding and/or shelter. Of these 15 species at least partially dependent on wetland/riparian habitat, 11 are upper-trophic level vertebrate predators. We therefore expect that potential increases in abundance of these species will only occur slowly, as they must await recovery of lower-level carnivores, herbivores and supporting native vegetation.

d. *Fish*

The coho salmon has been petitioned for listing under the Endangered Species Act, and is a candidate for listing by the state.

5. <u>Jurisdictional Wetlands</u>

Caltrans performed field surveys and mapped the wetland areas that would be under the jurisdiction of the COE under Section 404 of the Clean Water Act. Wetlands were mapped according to the methods described in the Corps of Engineers Wetland Delineation Manual (COE, 1987). The mapped wetland boundaries have been field-checked by the COE, but are yet to be finalized pending final COE review of documentation of the delineation provided by Caltrans.

Figure IV-40 shows the boundaries of the identified jurisdictional wetlands. These include salt marsh between the tidal lagoon and the picnic areas, seasonal wetlands and drainages in the Green Gulch pastures, and riparian wetlands along Redwood Creek. Included within the 33-acre study boundary are 9.1 acres of wetland, 0.8 acres of wetland/drainage, 5.8 acres of riparian wetland, 2.2

acres of waters of the United States, and 15.1 acres of upland. Most of the lower study area lies within jurisdictional wetlands, with the exception of the levees, the parking lot, and the upper portion of the Green Gulch pasture. Note that with the exception of Redwood Creek, most of these wetlands exist in their current form because of recent site modifications, and generally do not reproduce the historic functions of the pre-1800's natural system. Soil saturations and ponding in the pasture wetlands are currently artificially increased because the culverts that drain through the levees are blocked. If these were repaired, the extent of jurisdictional wetlands in the pasture would probably decrease.

C. LAND USE/RECREATION

This section describes major land uses influencing or potentially affected by proposed wetlands restoration (Figure IV-41).

1. Green Gulch Farm

Green Gulch Farm is a 111 acre private property within the boundaries of Golden Gate National Recreation Area, owned and managed by San Francisco Zen Center. A residential community of approximately 45 permanent residents lives at Green Gulch Farm. Zen training, meditation practice and meditation programs are the primary focus of the farm. A guest house and conference center and educational facilities accommodate the public and program participants. Between 10-15 acres are used for organic herb, flower, and vegetable gardens. Water supply for Green Gulch farm relies on use of the site's water resources, including developed springs and retention ponds.

Pasturing of approximately 12 horses from the adjacent horse stables is permitted on approximately 9 acres of the lowest fields of Green Gulch, and on the 9 acre hillside pasture between Highway 1 and Green Gulch Creek. A horse riding arena and small paddocks for temporary horse stabling are located on Green Gulch Farm lands near the intersection of Highway 1 and Pacific Way.

Public trails connecting to Muir Beach and the GGNRA trail system pass through or connect to Green Gulch Farm, including the Green Gulch Trail, Middle Green Gulch Trail, and Coastal Trail, the Redwood Creek levee trail, and a trail between Pacific Way and Green Gulch Farm.

2. Muir Beach Community

The Muir Beach community comprises approximately 150 residences located on the hillside above Muir Beach. The community also includes Green Gulch Farm, the Golden Gate Dairy horse stable, and the Banducci Flower Farm. The community of Muir Beach is surrounded by Golden Gate National Recreation Area lands, which include the flower farm and the Golden Gate Dairy stables on the east side of Highway 1. Muir Beach Community Services District is responsible for providing the community's water supply and fire protection, and for maintaining community roads and providing recreation. A community center is located within the residential area. The Muir

Beach Community Plan supports continued horse use on GGNRA land, and protection of Redwood Creek water quality from pollution. The plan acknowledges the natural values of Redwood Creek, and states that the Redwood Creek floodplain, including the lower Green Gulch fields, should be protected from development and allowed to flood in winter.

Water supply for the Muir Beach community is provided by wells adjacent to Redwood Creek near the Banducci Flower Farm.

Community issues related to the wetlands restoration have been identified through community meetings sponsored by the Golden Gate National Recreation Area. Key community issues include the desire to retain horses at Golden Gate Dairy, interest in resolution of traffic and parking congestion along Pacific Way, addressing flooding related to the public parking lot at Muir Beach, possibility of increased mosquitos as a result of wetlands restoration, loss of existing habitat values, support for wetlands restoration and restoring the creek to its natural alignment, retaining the levee trail and loop trail options, increasing pet control.

3. Golden Gate Dairy Horse Stables

The Golden Gate Dairy is a horse boarding facility which uses 188 acres of GGNRA land under a special use permit, 2 acres (including a residence and barns) of leased GGNRA land, and approximately 18 acres of leased Green Gulch land. Forty-three horses are presently boarded at this facility, including several owned by members of the Muir Beach community. Lessons are provided to the public 2-3 times a week, and space for overnight horse boarding and short term paddock space is available to the public in paddocks on Green Gulch land adjacent to Pacific Way. In addition to the horse facilities, the Dairy provides an important community gathering place, is the location for the county bookmobile stop, and hosts a regular vet clinic for horses as well as other community pets. The Muir Beach Volunteer Fire Department uses a building at this site for its headquarters, and its fire engine.

4. Banducci Flower Farm

Approximately 180 acres of land are leased from GGNRA by the Banducci Flower Farm, in a continuation of a long term agricultural use. The present permit for this operation expires in 1994, and the term for extension of this use has not been determined at this time. Irrigation for the flower fields is from wells adjacent to Redwood Creek.

5. Golden Gate National Recreation Area

GGNRA lands surround the community of Muir Beach, and include the hills above Green Gulch Farm, The Golden Gate Dairy, Slide Ranch, the Banducci Flower Farm, and approximately 25 acres at Muir Beach. Muir Beach is a popular park destination. A 200 car parking lot, picnic tables and a restroom provide facilities for the more than 400,000 visitors/year to this site. Trails from Muir Beach connect to GGNRA and Mt. Tamalpais State Park lands, and are used by hikers, bicyclists and equestrians. The GGNRA General Management Plan identifies its lands at Muir Beach as a Natural Landscape Management Zone, where natural resources and processes will remain as undisturbed as possible, and management activities will focus on protection of wildlife and vegetation form overuse and misuse. Green Gulch Farm is within a Special Use Zone, which includes lands not expected to be acquired in the foreseeable future because of compatible land management practices. Redwood Creek and Big Lagoon have been identified as unique and threatened resources of the park in the Natural Resource Management Plan, and have been the subject of studies to identify needed management actions.

6. Existing Uses of the Proposed Wetlands Restoration Site

The site proposed for wetlands restoration is comprised primarily of lands owned by San Francisco Zen Center, as part of Green Gulch Farm. Although the entire site is within GGNRA boundaries, less than 2 acres of the proposed wetlands site is owned by the National Park Service.

Green Gulch Farm currently leases approximately 9 acres of the proposed wetlands site to Golden Gate Dairy for pasturing of horses, a riding arena, and paddocks for short term (day or overnight) use. Although there is no formal lease agreement, it is understood that this use would be allowed to continue through March 1999. Four horses are kept on this site year-round, and 8 horses are rotated to an adjacent hillside pasture for 6 months between January and June each year.

Green Gulch Farm has used the lower 2 fields (Fields 6 and 7, Figure IV-41) for agricultural use (organic vegetable garden) in recent years, and intends to use them again for this purpose.

The proposed wetlands site is encircled by well used trails, including a popular trail along the levee, which also provides emergency vehicle access to the GGNRA trail system south of Muir Beach, a trail between Pacific Way and Green Gulch Farm, and the Green Gulch Trail.